

Forests and Climate Change

California's forests are an important contributor to global carbon cycles and help to regulate climatological changes. Scientists have generally agreed that the earth's climate is changing, in part due to human activities altering the chemical composition of the atmosphere through the buildup of greenhouse gases. These gases—primarily carbon dioxide (CO₂), methane, and nitrous oxide—trap heat. Carbon is the main component of efforts to reduce greenhouse gas because it is most abundantly emitted. Although uncertainty exists about exactly how earth's climate responds to these gases, global temperatures are rising.

Forests play an interesting and important role in the earth's carbon cycle. On one hand, the loss of forests worldwide to other uses (deforestation) is responsible for up to one-third of carbon emissions into the atmosphere and ranks second only to the burning of fossil fuels as a source of CO₂ emissions. On the other hand, forests serve as a large carbon sink. They capture CO₂ from the atmosphere through photosynthesis and store it as carbon in wood and other carbon-based compounds in the soil, understory plants, and in litter on the forest floor. Large amounts of additional carbon are stored in U.S. forests, including those in California.

To help summarize information on the role of California's forests and rangelands relating to climate regulation and global carbon storage, this section reviews the following topics:

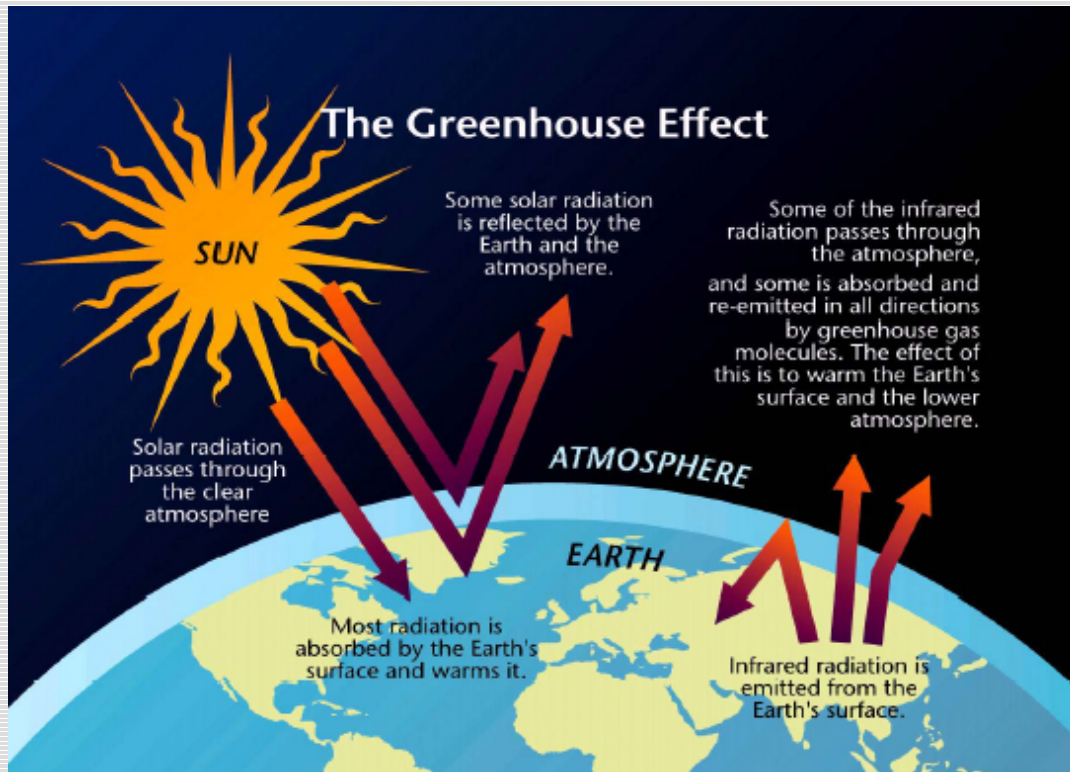
- introduction to relationship of climate change and CO₂ generation;
- the affects of climate change on forest resources;
- role of forests in regulating climate through carbon sequestration; and
- policy implementation and management opportunities including carbon trading; management tradeoff; afforestation, deforestation, reforestation, and age class distribution; monetary benefits from sequestration; and sequestration strategies.

Findings on trends in climate change

Climate change refers to long-term fluctuations in temperature, precipitation, wind, and other elements of the earth's climate system. The Intergovernmental Panel on Climate Change (IPCC) defines climate change as "any change in climate over time, whether due to natural variability or because of human activity" (IPCC, 2002). An ever-increasing body of scientific research attributes a significant portion of these climatological changes to greenhouse gases (GHGs). Greenhouse gases include such compounds as carbon dioxide (CO₂), methane (CH₄), and nitrous oxides (NO_x). These gases trap heat and cause other changes in the chemical composition of the atmosphere creating the "greenhouse effect" (U.S. Environmental Protection Agency (EPA), 2002).

The greenhouse effect: This effect, similar to a greenhouse, occurs when the atmosphere captures greater quantities of heat (Figure 1).

Figure 1. The greenhouse effect



Source: National Assessment Synthesis Team, 2001

Since the beginning of the Industrial Revolution, atmospheric concentrations of CO₂ have increased nearly 30 percent, NO_x concentrations have increased by about 15 percent, and CH₄ concentrations have more than doubled. Scientists believe that much of the increase of these gases has been caused by human activities. For example, fossil fuels burned to run cars and trucks, heat homes and businesses, and power factories are responsible for about 98 percent of the United States' CO₂ emissions, 24 percent of CH₄ emissions, and 18 percent of NO_x emissions. Increased agriculture, deforestation, landfills, industrial production, and mining also contribute a significant share of emissions. In 1997, the U.S. emitted about one-fifth of total global GHGs (Field et al., 1999).

In California, CO₂ emissions account for about 85 percent of in-state GHG emissions (the other sources are CH₄, NO_x, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride). Ninety-eight percent of those emissions are attributed to the combustion of fossil fuels. In terms of total CO₂ emissions from fossil fuel combustion in California in 1999, transportation accounts for the largest portion of emissions (58 percent), followed by power production (16 percent), non-power production industrial activities (13 percent), the residential sector (nine percent), and the commercial sector (four percent) (Franco, 2002).

Estimating future emissions: Estimating future emissions is difficult because it depends on demographic, economic, technological, policy, and institutional developments. Several emissions scenarios have been developed based on differing projections of these underlying factors. For example, by 2100, in the absence of emissions control policies, CO₂ concentrations are projected to be 30 to 150 percent higher than today's levels (National Assessment Synthesis Team, 2001).

Findings on ability to predict impacts of possible climate changes

Temperature and precipitation

The increasing concentration of GHGs is likely to accelerate the rate of climate change, especially in the realms of temperature and precipitation. A number of changes are possible, including extremes and variability. Global mean surface temperatures have increased one half degrees to one degree Fahrenheit since the late 19th century. The 20th century's 10 warmest years all occurred in the last 15 years of the century (National Assessment Synthesis Team, 2001). Of these, 1998 was the warmest year on record. Scientists expect that the average global surface temperature could rise one to four degrees Fahrenheit in the next 50 years and two to 10 degrees Fahrenheit in the next century, with significant regional variation.

Over the last few decades, worldwide precipitation over land has increased by about one percent and the frequency of extreme rainfall events has increased. The snow cover in the Northern Hemisphere as well as floating ice in the Arctic Ocean has decreased. Over the past century, the global sea level has risen four to eight inches. Evaporation will increase as the climate warms, which in turn increases the average global precipitation. Soil moisture is likely to decline in many regions and intense rainstorms are likely to become more frequent (National Assessment Synthesis Team, 2001).

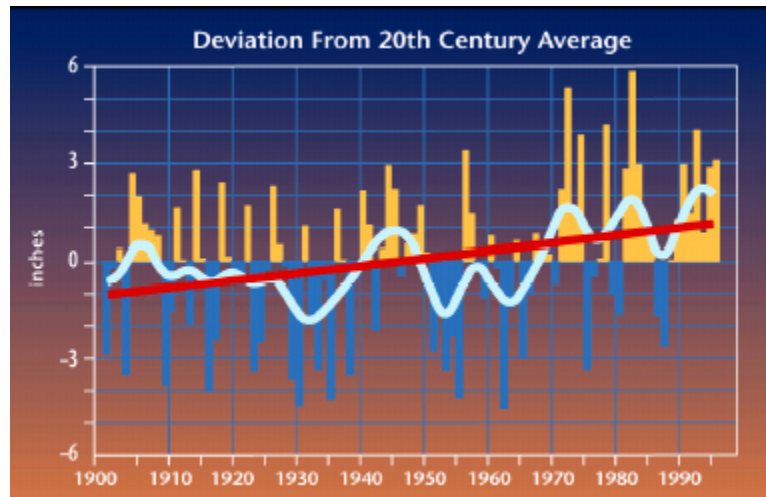
Observations from 1,200 weather stations across the U.S. show that temperatures have increased over the past century on average by almost one degree Fahrenheit. The coastal Northeast, the upper Midwest, the Southwest, and parts of Alaska have experienced increases in the annual average temperature, approaching an increase of four degrees Fahrenheit over the past 100 years (U.S. Global Change Research Program, 2002). The rest of the nation has experienced less warming. The Southeast and southern Great Plains have actually experienced a slight cooling over the 20th century; however, since the 1970s these two areas have had increasing temperatures as well. The largest observed warming across the nation has occurred during winter. Average warming in the U.S. is projected to be somewhat greater than other locations through the 21st century.

Prediction of rising temperatures across much of the United States: Two primary models are currently used in climate change projections. They are the Canadian Model and the Hadley Model, with the Canadian Model projecting slightly greater changes. In the Canadian Model scenario, increases in annual average temperatures of 10 degrees Fahrenheit by the year 2100 occur across the central U.S. with changes about half this large along the east and west coasts. Seasonal patterns indicate that projected changes will be particularly significant in winter, especially at night. In the Hadley model scenario, the eastern U.S. has temperature increases of three to five degrees Fahrenheit by 2100 while the rest of the nation experiences increases of up to seven degrees Fahrenheit, depending on the region (National Assessment Synthesis Team, 2001).

Changes in precipitation are another critical factor affecting climate change. Average U.S. precipitation has increased by 5 to 10 percent over the last century with much of that due to an increase in the frequency and intensity of heavy rainfall (Figure 2). Precipitation increases have been especially large

in the Midwest, southern Great Plains, and parts of the West and Pacific Northwest. Decreases were observed in the northern Great Plains.

Figure 2. U.S. national precipitation

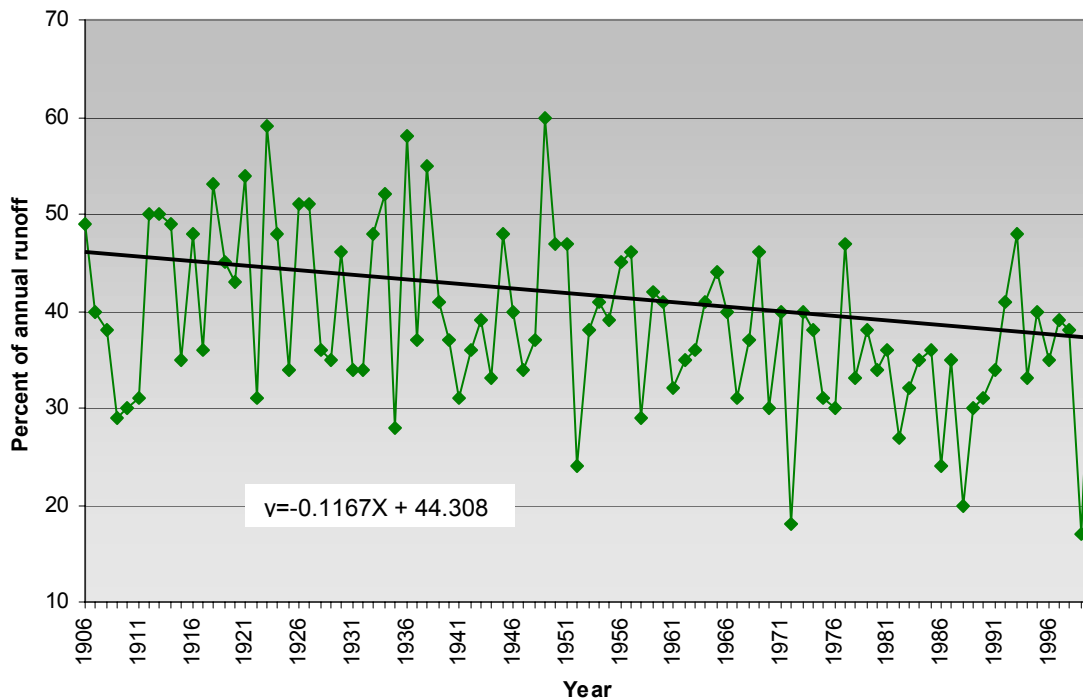


Source: National Assessment Synthesis Team, 2001

Recent reports based on climate change scenarios have suggested that California will be subjected to increased wintertime precipitation and decreased summertime streamflow (Field et al, 1999). This would continue trends already in effect. For example, over the last century there has been a trend toward less runoff in April to July, as well as a wide range of unimpaired runoff in the Sacramento River (Figure 3). This could reflect a number of factors, including increased temperature and changes in snow pack conditions.

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Figure 3. Sacramento River index, April to July runoff (percentage of annual runoff)



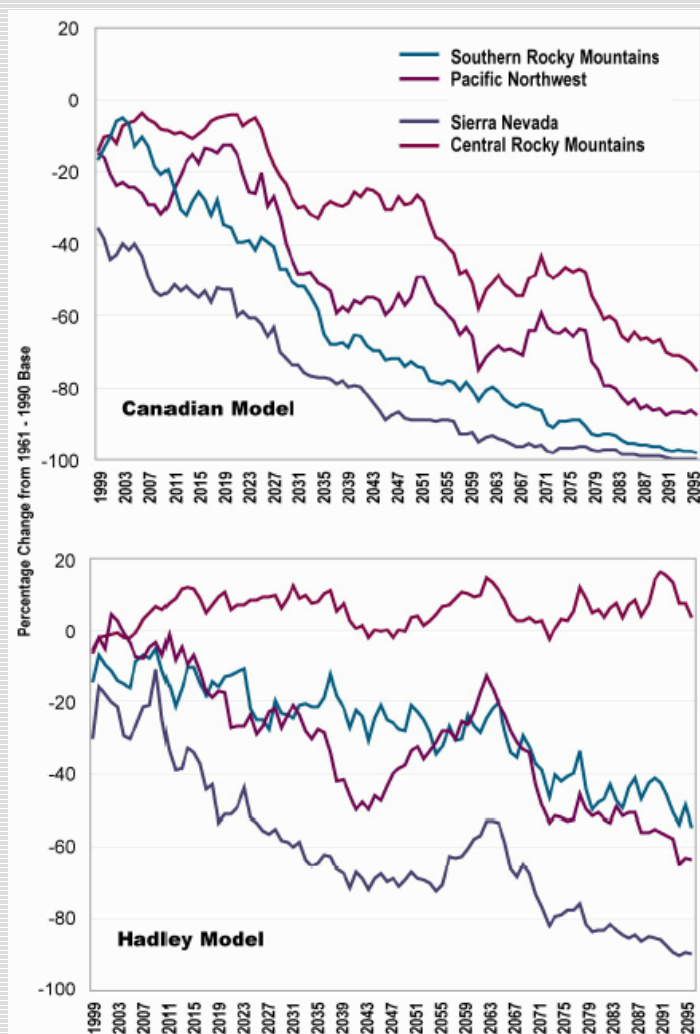
Source: Dettinger and Cayan, 1995

In a more focused effort, calculations were performed for a set of California river basins that extend from the coastal mountains and Sierra Nevada northern region to the southern Sierra Nevada region. Results from this study indicate that for all cases, a larger proportion of the streamflow volume will occur earlier in the year. The amount and timing is dependent on the characteristics of each basin, particularly the elevation of the freezing line (Wilkinson, 2002).

Predicting changes in precipitation and snow: In both the Hadley and Canadian models, most regions are projected to experience an increase in the frequency of heavy precipitation events. This is especially notable in the Hadley Model, but the Canadian Model shows the same characteristic. In both cases, these models project an increase in precipitation for California and the Southwest. The changes for California are predicted to be significantly greater than those for the eastern United States.

While the actual amounts are modest, the large percentage increases in rainfall projected for the Southwest are related to increases in atmospheric moisture and storm paths. A warmer Pacific Ocean would pump moisture into the region and there would be a southward shift in Pacific Coast storm activity. In the Sierra Nevada and Rocky Mountains, much of the increased precipitation is likely to fall as rain rather than snow, causing a reduction in mountain snow packs (Figure 4). This would tend to increase wintertime river flows and decrease summertime flows in the West. Across the Northwest and the central and eastern U.S. the two model projections of precipitation change are in less agreement. These differences will be resolved only by improvements in climate modeling.

Figure 4. Current and projected changes in Western snowpack, Canadian and Hadley models, 1999-2095



Source: National Assessment Synthesis Team, 2001

Calculations of climate change for specific areas are much less reliable than global ones, and it is unclear whether regional climate will become more variable. This is due to the models currently used to project climate change. Current models have an inherent weakness not only in data availability but also in use of variables.

Findings on the affects of climate change on forest resources

California has a wide range of forest and hardwood related ecosystems. It is a transition area between very wet, highly productive forest sites in the north to very dry, marginal forest areas in the south. In itself, this geography and ecology makes predicting the impact of climate change difficult. For California and other western states, scientists have been investigating the impact of environmental changes on forest ecosystems through field observation, controlled experiments, historical records, and computer-based modeling (Smith et al., 2001a; Wilkinson, 2002). Areas of possible change include:

- alteration in the growth and geographic range of different forest types;
- increases in the frequency of fire and insect outbreaks;
- changes in the carbon storage function of forests (e.g., from sinks to sources);
- evaluation of the importance of multiple stresses (ozone, nitrogen deposition, land use change) that work in concert with climate change; and
- changes in human interactions with forests (e.g., risk to settlements, recreational use).

Evaluations of these potential impacts of climate change are based on modeled scenarios. Though much progress has occurred in the area of models, there are still significant uncertainties in quantification and relationship of variables. However, the basic premise is that climate change can alter the function of forests and other natural processes.

Growth and geographic range

The shift in temperature together with a change in amount of precipitation, snow/rain ratio, and timing of available moisture are expected to affect plant growth. Temperature shifts can either increase or decrease plant growth. On the contrary, elevated CO₂ levels spur growth.

In California, the dominant factors are the availability of soil nutrients and water. Many of the State's plant species at the margin of their ecological ranges or on lower productivity sites may be sensitive to drought or changes in precipitation. Future changes in the summer dry period are likely to have impacts on plant growth that are at least as large as, and probably greater than, the changes in temperature or CO₂. Increases in winter precipitation may do little to increase summer soil moisture, unless a shift in timing extends the rainy season and the period of wet soils. Greater evaporation in a

In regions where neither water nor nutrients are severely limiting to plant growth, elevated CO₂ is likely to enhance forest production.

warmer climate is likely to cause greater drying of soils. Thus, summer drought stress may become increasingly important for plant productivity in California, unless the loss of soil moisture can be offset by the water-conserving responses of plants to elevated CO₂.

With decreased summertime streamflow, drought stress may become increasingly important for plant productivity in California.

Even if this level of stimulation persists for only a few years after seedlings are established, the cumulative nature of plant growth ensures that the stimulation could still have a dramatic effect on the time it takes the trees to reach harvestable size or in their ultimate size at maturity. In the Sierra Nevada, modeling experiments have predicted small increases in the total plant material produced per year. However, in places where warming leads to increased drought or where soil nutrients are limited, forest production may not be stimulated, and it could decline.

As climate conditions change, the map of vegetation types will shift along with the range of associated wildlife species. Tracking where ecosystems will move in a warming climate is not straightforward because species move individually. Furthermore, their fate may be altered by changes in the availability of water and nutrients or patterns of fire, drought, or pest attack. Models suggest that the arid shrublands of California's foothills may give way to grassy savannas, while shrubs replace forests on higher slopes. Trees, in turn, may gain ground upslope. Conifers may be replaced by hardwoods, potentially leading to a net increase of hardwood forests and a net decrease in conifer forests (Wilkinson, 2002).

In many parts of California, air pollution, fragmentation of the landscape by human development, and invasion by non-native species may limit the reestablishment of native ecosystems. Many resident species rely on given cold periods to determine periods of dormancy, growth, flowering, and reproductive cycles. Warmer temperatures will disrupt these cycles and the ability of plants and animals to reproduce and survive longer summer droughts.

In the north coastal habitats of California, fog is a defining component of the water cycle. Coastal fog and coastal redwoods are partners, with redwoods effectively gathering their summer moisture from the fog. More than 30 percent of the water reaching the soil and more than 10 percent of the water annually lost to the air by a redwood comes from fog. The fog that collects on the leaves then drips to the soil as moisture for the trees. If an increase in the frequency of El Niño events or a decline in the upwelling of cold water near the coast caused a major decrease in coastal fogginess, the result could be stress and eventual elimination of coastal redwoods. This remains a subject of great uncertainty. Under some climate change scenarios, coastal upwelling could actually increase and lead to increased fog (Field et al., 1999).

Increases in the frequency of fire and insect outbreaks

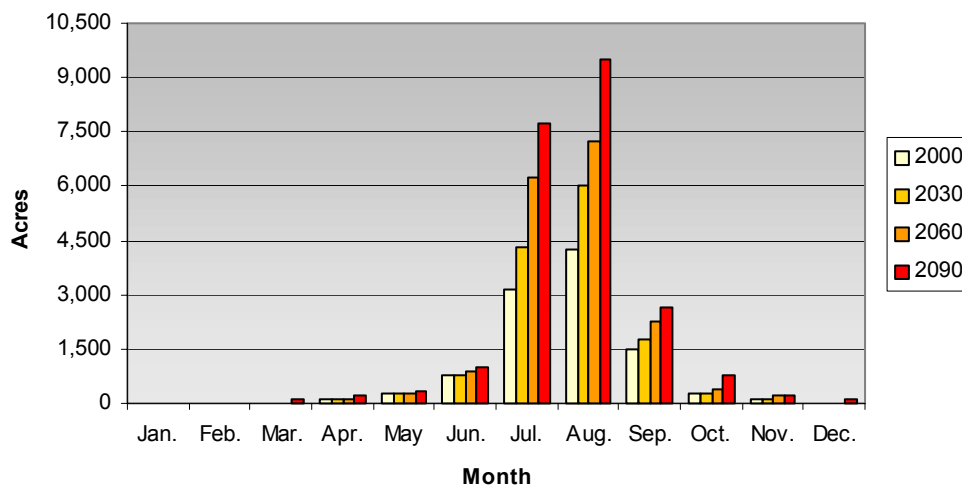
As in other California ecosystems, changes in the pattern of fires, disease, or pest outbreaks due to climate change have the potential to modify or conceivably even reverse the predicted responses of forests to elevated CO₂ levels and warming. Computer simulations indicate that a combination of warming, drying, and increased winds could lead to large increases in loss to wildfires in the future. Great uncertainty remains in predictions of future fire patterns largely because most fires in California occur under extreme rather than average weather and climate conditions, and climate models do poorly at predicting extreme events such as Santa Ana winds.

Fire is a key evolutionary force in California's wildland ecosystems. Fire history in the Sierra Nevada shows that in the pre-European settlement period surface fires recurred every five to 10 years in woodlands and grasslands, every four to 20 years in pine and mixed conifer forests and every 15 to 40 years in higher elevation red fir forests. Coastal redwood forest understory fires burned with a return

frequency of six to eight years. Crown fires reoccurred in the redwood type on a 20 to 80 year return interval. Since 1850, fire patterns in virtually all upland ecosystems in California have been altered by climate change, land use change, and intensive fire suppression strategies. The effects of changes in fire suppression strategies in the pine and mixed conifer forests have been some of the most dramatic. As a result, tree densities have increased and thick understories of white fir and other shade-tolerant species now promote the spread of fire up into the canopy, leading to catastrophic crown fires.

Fire behavior models predict a sharp increase in both ignition and fire spread under warmer temperatures combined with lower humidity and drier fuels (Figure 5). The most severe effects will occur if model forecasts project an expansion of mixed conifer and a corresponding reduction in the red fir forest that occupies the next elevation zone. Fire is predicted to increase both in frequency and size.

Figure 5. Projected mean area burned in the Sierra Nevada burned, 2000, 2030, 2060, and 2090



Note: Modeled mean monthly acres burned show large percentage increases; with July and August mean area burned more than double by 2090. These months show an increase of about one third per scenario (2030, 2060, 2090).

Source: Wilkinson, 2002

Changes in carbon storage function of forests (from sinks to sources)

Forests both store carbon (in roots and vegetation) and give off carbon (via decomposition or wildfire). More productive forests could potentially store more carbon. At mid-latitude forests, such as those in northern California, there is a consensus emerging that site-specific conditions as well as history, human management, air pollution, and biotic effects (e.g., herbivory) are much stronger controllers of forest productivity, decomposition, and carbon balance than climate change or CO₂ enrichment (Aber et al., 2001).

Although forest productivity is most affected by human causes, carbon storage in absolute terms is highly dependant on the age class structure. Generally, forests with older age class structures store more carbon (in terms of total storage) than younger forests, both on an annual and cumulative basis (Wayburn et al, 2000).

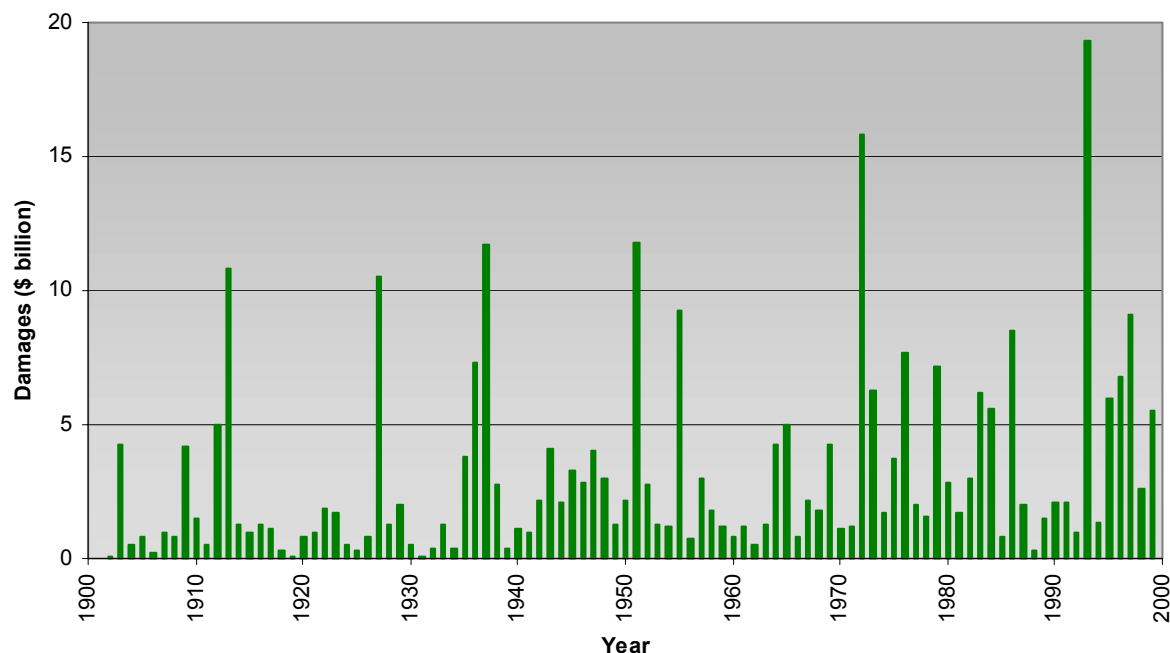
Multiple stresses (ozone, nitrogen deposition, land use change)

Evidence for climate change effects on forest ecosystem “services” (e.g., functions that are important to productivity, environmental quality, and other human concerns) are beginning to emerge in North America. Climate warming may increase soil acidification and nitrate ion (NO_3) concentrations, especially in forests with a history of high nitrogen deposition. To date, forests have been able to absorb nitrogen deposits from elevated CO_2 levels, however, the ability of forests to continue to absorb excess nitrogen and CO_2 is not at all certain (Wilkinson, 2002). Overall, the effects of climate change on biogeochemical processes are likely to be small relative to other factors such as land use history and atmospheric chemistry (smog/ozone pollution) (Aber et al., 2001).

Human interactions with forests (e.g., risk to settlements, recreational opportunities, etc.)

A number of studies have suggested risk to humans associated with global climate change impacts in California. Increased risk to humans comes from the fact that forest fires could become more frequent and severe. Damage to trees from insects and pests, especially in urban areas, could be greater. There is also a greater chance that some diseases will spread more easily in a warmer, wetter climate (Smith et al., 2001a). In addition, shifts in precipitation falling as rain instead of snow could increase localized flooding events. This will damage transportation systems as well as personal property (Figure 6). A second kind of impact is the potential economic impact on forest-related industries. Commercial forestry is a substantial industry in California. Hence, factors that relate to the sustainability of commercial species and the market for forest products are important, particularly with respect to rural regional economies.

Figure 6. Cost of flood damages, 1900-2000 (constant dollars)



Source: National Weather Service, 2002

In general, scientists predict that climate change may have a beneficial effect on the world's forests. Ecosystem changes will be reflected in increased timber supply impacts resulting from CO₂ growth stimulus. Ecological change is both slow and dynamic. Capturing how timber supplies and markets respond requires a long time frame of analysis (Sohngen and Mendelsohn, 1998; Sohngen et al., 2002).

For a variety of reasons, it is reasonable to presume that climate change will have an impact on timber net revenue in California. In one analysis using a global timber model, the conclusion was California timber suppliers would likely be more vulnerable to global price reductions from increased global production than to production reductions in the State (Sohngen et al., 2002). If there are no changes in prices, the State climate effects could be slightly beneficial to timber producers and could even deliver benefits as high as one billion dollars. However, if prices fell because of global increases in forest productivity, California timber suppliers could suffer damages that could easily exceed one billion dollars. The study also noted that the same price reductions that could hurt timber suppliers would provide large benefits to California consumers. This gain to consumers would be well in excess of the loss to suppliers, perhaps between a total of \$13 and \$14 billion over the next century (Sohngen et al., 2002).

Climate change could hurt timber suppliers through increased supplies, but be beneficial to consumers through lower prices.

Findings on role of forests in regulating climate through carbon sequestration

Forests play an important role in the earth's carbon cycle. On one hand, the loss of forests on a global scale to other uses (deforestation) is responsible for up to one-third of carbon emissions into the atmosphere and ranks second only to the burning of fossil fuels as a source of CO₂ emissions (Wilkinson, 2002). On the other hand, forests serve as huge carbon sinks.

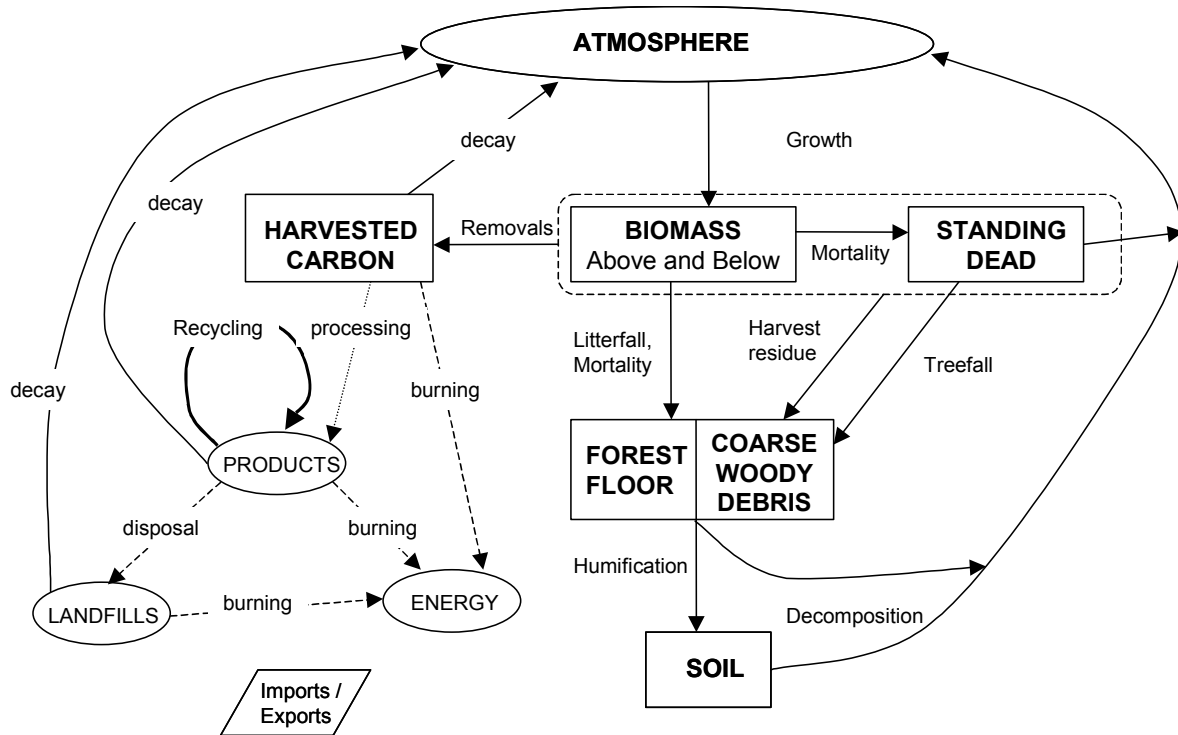
They capture CO₂ from the atmosphere through photosynthesis and store it as carbon in wood and other carbon-based compounds in soil, understory plants, and litter on the forest floor. Large amounts of additional carbon could be stored in forests through afforestation, reforestation, and practices to enhance the growth rate of trees in existing forests.

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Land use change, not climate change or atmospheric chemistry, has been, and probably will continue to be, the most important determinant of carbon storage, uptake, and release into terrestrial ecosystems (Birdsey et al., 2000)

Forest carbon is generally reported in terms of above and below ground tree components, understory vegetation, forest floor litter, and soil. The carbon cycle involves carbon fluxes between the atmosphere, oceans, and terrestrial biosphere, with active reserves transferred through biological, physical, and chemical mechanisms (Field et al., 1999) (Figure 7). Processes that accelerate carbon sequestration have historically balanced processes that naturally increase the emission of CO₂. This yields little change to atmospheric CO₂ levels (U.S. Department of Energy (DOE), 1999). However, the current large increase in atmospheric CO₂ implies that CO₂ emissions exceed carbon sequestration (DOE, 1999).

Figure 7. Forest sector carbon flows



Source: Birdsey and Lewis, 2001

Forest soils appear to be the best available long-term option for storing carbon in terrestrial ecosystems because the residence time of carbon in soils is much longer than in aboveground biomass (DOE, 1999). Approximately 50 to 60 percent of the carbon in temperate forest ecosystems is found in soil organic matter (SOM) (DOE, 1999). Soils with high concentrations of carbon in SOM have improved nutrient absorption, retention, and resistance to erosion; these are factors especially important for forest productivity and carbon sequestration (Johnson, 1992; DOE, 1999). However, understanding and quantifying soil carbon pools has been complicated by a lack of available data, such as the effects of different temperature scenarios on soil carbon.

Although forest soils represents a location for carbon storage, above ground growing stocks likely will provide a more immediate and manageable means to store carbon. This is due to the relatively long time frames needed to manage soil carbon storage and the relative shorter period offer by tree growth and forest stand manipulations to store carbon via prompting vigorous growth.

Land management practices and land use changes can directly affect the ability of soils to sequester carbon. Practices that protect soil and reduce erosion greatly improve the potential of those soils to sequester carbon (DOE, 1999). Converting cultivated land to forests provides an important carbon sink. There are clearly opportunities to increase carbon storage in soil through reforestation of former agricultural or rangeland and adoption of forest management practices like fertilization and genotype improvement that increase net rates of biomass production (Johnson, 1992). Practice such as fertilization, which can generate GHG during its production, should be evaluated based on the entire sequestration/emission accounting cycle for full determination of net sequestration benefits.

For purposes of estimating carbon sequestration potentials, ecosystem carbon is partitioned into three separate components: biomass, forest floor, and soil. Harvested carbon is treated separately from ecosystem carbon. The definitions of these components are broad enough to include all sources of organic carbon in the forest ecosystem. Biomass includes all aboveground and belowground portions of all live and dead trees and understory vegetation, including the merchantable stem, limbs, tops, cull sections, stump, foliage, bark and rootbark, and coarse roots (greater than two millimeters in diameter). The forest floor includes all dead organic matter above the mineral soil horizons except standing dead trees, litter, humus, and other woody debris. The soil component includes all organic carbon in mineral horizons to a depth of one meter, excluding coarse roots. Harvested carbon includes carbon removed from the forest for wood products and fuelwood. Each of the component pools is related through transfers of carbon.

Another way to manage carbon storage is to do so in wood products. This can be done in a number of ways. One approach is to shift the product mix to a greater proportion of lignin containing solid wood, paper, and paperboard products that decay less in landfills (Row and Phelps, 1996). Maximizing the amount of carbon in products through efficient utilization of raw material, increasing the use of by-products for energy substitution, and ensuring that unused by-products are disposed of in sealed landfills will minimize the amount of CO₂ emitted (Skog and Nicholson, 2000). These methods focus on the transfer of carbon from live biomass to non-living wood products and do not actually sequester carbon. It is the manipulation of the stored wood products to slow decay that results in decreased decomposition emissions and thus increase the accounting balance of stored carbon.

An extensive and comprehensive forestry data collection, management, and reporting system underlies carbon estimates and analyses (Powell et al., 1993; Smith et al., 2001b). This information allows estimates for carbon stock changes on forest land in California (Table 1).

Table 1. Total carbon stock on forest lands and annual change by forest type 1987, 1992 and 1997 (million metric tons of carbon)

Forest type	1987	1992	1997	Average annual change		
				1987-1992	1992-1997	1987-1997
Douglas-fir	195.9	243.2	290.2	9.46	9.40	9.43
Ponderosa pine	497.7	626.5	757.8	25.76	26.25	26.01
Western white pine	0.4	15.5	30.7	3.02	3.03	3.03
Fir-spruce	810.7	636.3	455.5	-34.88	-36.17	-35.52
Hemlock-Sitka spruce	4.5	3.3	2.1	-0.24	-0.24	-0.24
Lodgepole pine	72.4	54.2	36.1	-3.62	-3.62	-3.62
Redwood	169.6	151.2	131.0	-3.68	-4.03	-3.85
Other hardwoods	673.1	658.7	645.5	-2.87	-2.64	-2.76
Other forest types	104.0	326.5	549.0	44.51	44.49	44.50
Pinyon-juniper	203.6	159.4	114.9	-8.84	-8.89	-8.87
Chaparral	606.8	485.4	364.0	-24.28	-24.28	-24.28
Non-stocked	6.2	13.4	20.4	1.43	1.40	1.42

Source: California Energy Commission (CEC), 2002

Over the last decade, California's forests have been a net sink of carbon (Birdsey and Lewis, 2001). This suggests that carbon sequestration through forest growth and retention of older age class forests were greater than carbon loss through forest clearing, fire, harvest, and decomposition.

Storage as live biomass made up most of the sequestration from 1990-1999. Carbon was also stored in wood products and wood in landfills. Decomposition from the forest floor and coarse woody debris

resulted in carbon lost to the atmosphere. The same was true with loss of carbon from soils especially when land is converted from a growing forest to another land use. On an average annual basis from 1987-1997, over 5.2 million tons of carbon were added to the carbon stock on forest land (Table 2). The largest increases in carbon stocks were in live biomass and wood products. The amount of carbon on forest floors and in soils decreased slightly, although this is likely the result of reclassification of forest types and lack of consistent age class information rather than a true loss of carbon.

Table 2. Total carbon stock on forest lands and annual change by accounting component 1987, 1992 and 1997 (million metric tons of carbon)

Accounting component	1987	1992	1997	Average annual change		
				1987-1992	1992-1997	1987-1997
Biomass	963.5	988.7	1,014.1	5.04	5.09	5.06
Forest floor and coarse woody debris	685.8	678.7	670.8	-1.42	-1.58	-1.50
Soils	1,554.1	1,549.8	1,545.7	-0.85	-0.83	-0.84
Wood products and landfills	141.6	156.5	166.7	3.00	2.03	2.51
TOTAL	3,344.9	3,373.8	3,397.3	5.77	4.71	5.24

Source: CEC, 2002

Carbon stocks increased on other public and forest industry lands and decreased on National Forest and other private ownership categories (Table 3).

Table 3. Total carbon stock on forest lands and annual change by owner 1987, 1992 and 1997 (million metric tons of carbon)

Owner group	1987	1992	1997	Average annual change		
				1987-1992	1992-1997	1987-1997
National Forest	1,570.3	1,557.5	1,540.0	-2.56	-3.50	-3.03
Other Public	370.2	390.6	410.9	4.09	4.06	4.07
Forest Industry	303.2	330.7	357.0	5.48	5.27	5.38
Other Private	1,101.2	1,095.0	1,089.3	-1.24	-1.13	-1.19
TOTAL	3,344.9	3,373.8	3,397.3	5.77	4.71	5.24

Source: CEC, 2002

A factor in the decrease of total carbon stock on forest land is land use change. About 2.5 million tons of carbon is lost per year to various land use changes such as conversion to non-forest uses (Table 4).

Table 4. Annual change in carbon stocks on forest lands attributed to land use change by accounting component 1987, 1992 and 1997 (million metric tons of carbon)

Accounting component	Average annual change		
	1987-1992	1992-1997	1987-1997
Biomass	-1.47	-1.48	-1.48
Forest floor and coarse woody debris	-0.99	-0.99	-0.99
Soils	-1.07	-1.04	-1.05
Wood products and landfills	0.96	1.08	1.02
TOTAL	-2.57	-2.44	-2.50

Source: CEC, 2002

Findings on policy implementation and management opportunities

Carbon trading

Greenhouse gas (GHG) trading has its origins in the United Nations Framework Convention on Climate Change and was later advanced by the Kyoto Protocol in December 1997. Carbon trading is conceptually similar to emissions trading which has been an environmental economic instrument successfully used in the United States for sulfur oxide and nitric oxide emissions mitigation. Carbon trading is used to reduce costs and increase flexibility in reduction measures. Companies or individual projects that can achieve emission reductions at a lower marginal abatement cost than others can trade their surplus reductions with companies that face higher costs of achieving their reduction obligations.

Carbon emission trading is a practice that is still in its infancy. The emission trading market appears to be difficult to establish even in a single country. Emission trading markets depend on forecasts from economic models and these models significantly influence people's expectations about the costs. Despite much interest in greenhouse gas trading, the market that has developed thus far remains fragmented. Due to the variability and uncertainty of the final carbon market mechanisms, the prices have a wide range of value to date. The range of values in 1991 was \$0.60 to \$1.50 per ton of carbon for verifiable emission reductions and from \$2.14 to \$9.36 per ton of carbon in 2002 (Rosenzweig et al., 2002).

Within the U.S., policies on carbon trading are evolving on both the national and State levels in the form of GHG emission registries. These developments are mostly to ensure that companies who voluntarily reduce emissions can obtain appropriate credit in any future regulatory scheme.

On the federal level, the Bush Administration has directed that the current voluntary GHG registry (1605(b) program at U.S. Department of Energy) identify and implement changes to improve the credibility of results reported to that program. A multi-agency effort is underway to identify potential means of improving the 1605(b) program.

Some states are implementing mandatory GHG emissions reduction programs for individual sectors and allowing for emissions trading. Massachusetts, among other northeastern states, has implemented such a scheme for the electricity sector. California has just passed legislation to control GHG emissions from motor vehicles under an amendment to the Health and Safety Code (AB 1493, chapter 200, 2002) (Legislative Council of California, 2002a). This legislation contains provisions for the reporting of emissions reductions at the California Climate Action Registry (the Registry).

The California Registry was launched in October 2002. The private, non-profit organization has appointed officers and developed the initial protocols for registering GHG emissions. Currently, 23 participants have committed to join the registry in its first year of operation. The California Environmental Protection Agency and the CEC have already committed to participate. There were two major additions to registry mandates by the legislature in 2002, SB 812 and AB 1493 (Legislative Council of California, 2002a).

In coordination with Senate Bill 812 (Sher, Chapter 423, 2002), a statewide baseline is being developed to establish a baseline of carbon sequestration for terrestrial carbon in California forests and wildlands. The baseline is to only include carbon accumulated due to management practices over and above "business as usual". The California Department of Forestry and Fire Protection, in cooperation with the CEC, is directed to develop protocols and guidelines for implementation.

Reducing carbon deposition

National agenda

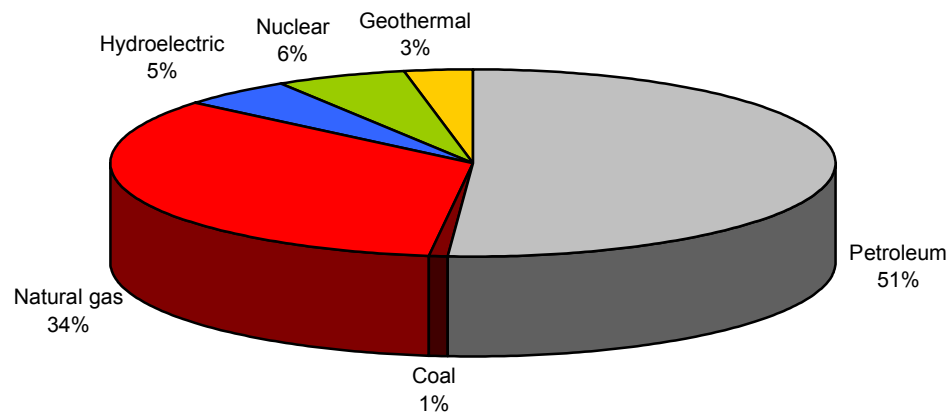
On February 14, 2002, President Bush committed the U.S. to an ambitious climate change strategy that will reduce domestic GHG emissions relative to the size of the American economy. The stated goal of this strategy is to reduce GHG emissions by 18 percent over the next 10 years.

California efforts on climate change

In California, several policy efforts in progress are targeted at dealing, at least in part, with climate change issues. These include the following: 1) smart growth; 2) green driving; 3) sustainable development; 4) green accounting; 5) the Registry; and 6) a joint agency climate team. The first four of these address energy production and usage and efficiencies for facilities and transportation. The policy efforts rely on a number of regulatory and non-regulatory approaches using energy policy, cost shifting, construction criteria, alternative energy technology investment, and subsidies for alternative energy technology marketing.

In 2002, the State legislature and the administration took several actions in chaptered legislation that will have short and long-term impacts on California climate change contributions. AB 1493 provided the California Air Resources Board the authority to regulate CO₂ tailpipe emissions (Legislative Council of California, 2002a). The bill deals with this primarily through the regulatory ability to mandate reduced fuel usage or use of alternative fuels. This will increase pressures on completion of technological developments for hydrogen fuel cells and biofuel use and production (Figure 8).

Figure 8. Percentage of energy supply by primary energy type



Source: CEC, 2003

SB 1038 and AB 57 address two of the institutional barriers to including a larger portion of renewable energy sources in the State's base energy load availability (Legislative Council of California, 2002b and 2002c) (see [Forest and Range Related Energy Industries](#)). The legislation required that renewable energy sources be increased to 20 percent of the electricity purchased and sold by Investor

Owned Utilities by the year 2017. This is commonly referred to as a Renewable Portfolio Standard. The second major institutional change is the concept of “net metering.” This requires utilities to purchase excess energy produced by private cogeneration facilities such as residences, government facilities and manufacturing facilities. Production and usage are monitored for a five-year period to establish a base from which excess energy is purchased.

Numerous forestry options to mitigate atmospheric buildup of CO₂ have been proposed. These options are categorized below according to whether their primary or direct effect is on emissions reduction, sink enhancement, or a combination of the two. Each of the options has indirect effects so that the three categories are not mutually exclusive. For example, forest management activities not only affect carbon storage in forest ecosystems but also affect the kind of products that may be produced from harvested wood. This in turn impacts energy use in two ways: 1) burning of by-products to substitute for fossil fuel; and 2) substitution of wood products for similar products that use different amounts of energy in the production process (Marland et al., 1997).

Emissions reduction

Reducing emissions is the most direct way to stabilize GHG concentrations in the atmosphere. Emission reductions result from management strategies that improve the quality of forest stands. Healthy stands sequester more carbon. Some wood products used in construction can be manufactured with less energy than non-wood substitutes, such as aluminum and concrete (Skog et al., 1996). To the extent that such substitution is practical and economic, an increase in use of these wood products and a corresponding decrease in their substitutes, reduces energy demand and associated emissions. The effectiveness of product substitution is based on a number of factors such as relative costs of inputs and elasticity of demand.

Reduce demand for energy in growing timber, harvesting, and wood processing

Energy is used in establishing plantations, managing forests, harvesting timber, and manufacturing wood products. Efficiency of energy use can be increased through engineering at each step in the manufacturing process. Adoption of more energy-efficient practices depends on economic evaluation (U.S. Congress, Office of Technology Assessment, 1991).

Reduce biomass burning (wildfires)

Protecting forests from wildfire maintains standing biomass or allows biomass to increase. In some cases, particularly in the western states, fire protection has resulted in overstocked stands and large amounts of biomass in dead and dying trees. This poses a substantial risk of mass catastrophic wildfire or other natural disturbances such as insect or disease outbreaks (Sampson and Clark, 1996). Both the long- and short-term consequences of fire protection must be considered in evaluating this option. Fire protection practices must include vegetation management that will reduce fire hazards while enhancing the potential to increase carbon storage (sink enhancement).

Sink enhancement

Sink enhancement technologies are designed to offset emissions by storing more carbon in forest ecosystems and storing carbon in wood products. Because much of the forest area in the U.S. is managed

for timber products on recurring cycles of harvest, regeneration, and growth, there are opportunities to increase the average amount of standing biomass while still producing wood products. The harvested carbon that ends up in wood products and landfills is usually counted as an addition to the total amount of carbon sequestered. During the manufacturing process, wood waste that is burned for energy is sometimes counted to the extent that wood fuel is substituted for fossil fuel. However, storage of carbon in wood products is generally not means of carbon sequestration, it simply slows the decay rate.

Afforest marginal cropland and pasture

Conversion of cropland and pasture to forest, either by tree planting or natural afforestation, usually increases the amount of carbon stored in biomass and soils relative to the previous land use (Sampson and Hair, 1992). If the new forest lands are managed for wood products, then the disposition of carbon in wood products, by-products, and landfills must also be considered. Large stretches of California riparian zones along major rivers, such as the Sacramento River, have been converted to either agriculture or grazing. Reestablishing riparian hardwood forests in these zones represents a significant opportunity to increase sequestration.

Reduce conversion of forest land to non-forest use (reduce deforestation)

Conversion of forest land to non-forest use usually means loss of all or a substantial part of live biomass as well as a reduction of organic matter in soils and on the forest floor (Houghton, 1996). Carbon dioxide and other greenhouse gases are emitted when the removed biomass and organic matter are burned or decomposed. Some carbon may be sequestered for a time in wood products if the removed biomass is utilized. Additionally, when land is converted to non-forest uses, it also means foregone future storage. When part of a mitigation strategy, controlling deforestation is sometimes referred to as protecting or conserving existing forests (Matthews et al., 1996). Land use institutions in California will need to be reevaluated for effectiveness in preventing forest conversion to other uses.

Improve forest management

There are opportunities to improve carbon storage by changing silvicultural practices on certain sites and forest conditions (Sampson and Hair, 1996). The magnitude of increased carbon storage may be difficult to quantify since silvicultural practices are usually developed and applied for another purpose, such as increasing timber growth, and will not necessarily increase biomass growth. Nevertheless, some forest stands may not be growing at biologically potential rates because of severe overstocking or understocking. These stands offer the best opportunities for enhanced carbon storage. Also, silvicultural practices may be designed to maximize the amount of carbon eventually stored in harvested wood products or recruitment of late successional stage stands. Carbon storage in absolute terms is highly dependant on the age class structure. Generally, forests with older age class structures store more carbon (in terms of total storage) than younger forests, both on an annual and cumulative basis (Wayburn et al, 2000).

Reduce harvest

The effectiveness of reducing harvest depends on temporal and spatial considerations. Reducing harvest can cause a short-term increase in the amount of carbon stored in forests because carbon loss to the atmosphere is avoided during the removal of biomass and wood processing (Heath et al., 1993). It also has long-term benefits because it not only prevents release of emissions from harvesting, but allows for the increased sequestration of carbon over a longer stand rotation.

In contrast, over the long-term a continuous cycle of harvest, efficient utilization of biomass, and regrowth can sequester more carbon than would be the case without harvesting (Sampson and Hair, 1996). The analysis should also address imports and exports between regions and countries since reduced harvest in one region may be offset by increased harvest elsewhere (increased imports) or by changes in wood processing technology.

Increase agroforestry

Agroforestry can add biomass to otherwise low-biomass agroecosystems. It can also reduce the need to clear forest land for agriculture (Schroeder, 1993). These carbon benefits can accrue along with increases in crop yields. One opportunity involves the reestablishment of hardwood riparian forests in areas where they have been removed and where the land no longer has other economic uses. Other opportunities exist with the conversion of poor quality rangeland or brush land to biomass farms for energy production. Though these will be shorter-rotation crops, they do store larger amounts of carbon for significant periods.

Substitute renewable biomass for fossil fuel energy

Short-rotation woody biomass crops may be grown specifically for energy production. When biomass is grown in a sustainable fashion and used to displace fossil fuels, net carbon emissions are avoided since the CO₂ released while converting the biomass to energy is sequestered in the re-growing biomass through photosynthesis (Rinebolt, 1996). Biofuels may be substituted for fossil fuels especially in the pulp and paper industry since it has access to waste biomass produced during manufacturing. There is not a one-to-one substitution because of differential conversion efficiencies and unpredictable energy markets. This approach ties in well with the current California Renewable Portfolio Standard, which states that renewable energy is to comprise 20 percent of all consumption by the year 2017.

Increase proportion and retention of carbon during the manufacturing process of durable wood products

After harvest, forest carbon passes through a series of conversion processes to yield wood products and byproducts (Row and Phelps, 1996). Maximizing the amount of carbon in products through efficient utilization of raw material, increasing the use of byproducts for energy substitution, and ensuring that unused byproducts are disposed of in sealed landfills will minimize the amount of CO₂ emitted (Skog and Nicholson, 1998). Increasing the life of products in use may result in less new timber harvested for replacement products, which would affect carbon storage in biomass.

Increase paper and wood recycling

Recycling wood fiber and wood products may reduce CO₂ emissions in two ways: 1) by reducing the area harvested to provide virgin fiber; and 2) by using less energy to convert recycled products versus growing, harvesting and processing virgin fiber (Skog et al., 1996). Paper recycling is already common. Most solid wood products are currently disposed of in landfills and debris dumps and not recycled.

Plant trees in urban and suburban areas

Trees affect urban climate by shading, reducing wind, and limiting evapotranspiration (McPherson and Rowntree, 1993; Nowak, 1993). Proper placement of trees and use of the correct tree species reduces the energy needed to heat and cool residential and small commercial buildings, with the magnitude of the energy reduction dependent on the local climate (Birdsey et al., 2000).

Glossary

afforestation: The establishment of a forest in an area where preceding vegetation or land was not forest (Helm, 1998).

anthropogenic: Of or relating to the study of the origins and development of human beings.

biofuels: Fuels made from cellulosic biomass resources. Biofuels include ethanol, biodiesel, and methanol.

biomass: Plant material that can be converted into fuel.

carbon sequestration: The ability of forests or other natural systems to “sink” or store carbon, thereby preventing it from collecting in the atmosphere as CO₂. Forests absorb carbon when they break down CO₂ during photosynthesis.

carbon trading: use of markets that have developed for investing in carbon sequestered in forests or other forms.

CDCF: Community Development Carbon Fund.

CEC: California Energy Commission.

CH₄: Methane.

CO₂: carbon dioxide.

diameter at breast height: Tree trunk diameters are measured at breast height, defined as the diameter of the tree 4.5 feet (1.37 meters) above ground on the uphill side of the tree. If a tree forks below breast height, each trunk is treated as a separate tree.

DOE: U.S. Department of Energy.

ecosystem services: the beneficial outcomes, for the natural environment, or for people, that result from ecosystem functions. Some examples of ecosystem services are support of the food chain, harvesting of animals or plants, clean water or scenic views. In order for an ecosystem to provide services to humans, some interaction with, or at least some appreciation by, humans is required.

EPA: U.S. Environmental Protection Agency.

evapotranspiration: loss of water by evaporation from the soil and transpiration from plants.

fire return intervals: the number of years between fire occurrence at a specific point on the ground.

fuelwood: trees or parts of trees harvested for use as fuel or firewood.

GCM: Global Climate Model.

GDP: See gross domestic product.

GEF: Global Environment Facility.

GHG: Greenhouse gas.

gross domestic product: the total market values of goods and services produced by workers and capital within the U.S. borders during a given period.

HARVCARB: Harvested Carbon Model.

humus: the part of dirt or soil which comes from organic matter, such as from dead and decaying plants and animal remains.

IPCC: Intergovernmental Panel on Climate Change.

lignin: a complex polymer, the chief noncarbohydrate constituent of wood, that binds to cellulose fibers and hardens and strengthens the cell walls of plants.

litter: the uppermost layer of the forest floor consisting chiefly of fallen leaves and other decaying organic matter.

MMBF: Million board feet.

MMT: Million metric tons.

MMTC: Million metric tons of carbon.

NOX: Nitrous oxide.

NO₃: Nitrate ion.

nutrient cycling: The exchange or transformation of elements among the living and nonliving components of an ecosystem.

O₃: Ozone.

the Registry: California Climate Action Registry.

riparian: relating to or located on the banks of a river or stream.

sawtimber: live trees of commercial species containing at least one 12 foot sawlog or two noncontiguous eight foot logs. Softwoods must be at least nine inches in diameter and hardwoods at least 11 inches in diameter.

seral: of or relating to an ecological sere (a seral stage; a seral community).

silviculture: generally, the science and art of cultivating (such as with growing and tending) forest crops, based on the knowledge of silvics. More explicitly, silviculture is the theory and practice of controlling the establishment, composition, constitution and growth of forests.

SOM: soil organic matter.

streamflow: flow of water in streams.

successional stage: a particular state of ecological development.

timberland: forest land capable of growing 20 cubic feet or more of industrial wood per acre per year (mean increment at culmination in fully stocked, natural stands). Timberland is not in reserve status through removal of the area from timber utilization by statute, ordinance, or administrative order and is not in a withdrawn status pending consideration for reserved.

understory: the trees and other woody species growing under a relatively continuous cover of branches and foliage formed by the overstory trees.

USDA: U.S. Department of Agriculture.

USFS: U.S. Forest Service.

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